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THE MANCHESTER

STEAM USERS' ASSOCIATION.

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MEMORANDUM BY CHIEF ENGINEER FOR THE YEAR 1902.

MANCHESTER
TAYLOR, GARNETT, EVANS, & CO., LTD., BLACKFRIARS STREET; ALSO AT REDDISH AND LONDON.
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MANCHESTER STEAM USERS' ASSOCIATION.

ACCUMULATED FUNDS, £26,000.

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MEMORANDUM BY CHIEF ENGINEER.

December 31st, 1902.

TO THE EXECUTIVE COMMITTEE.

GENTLEMEN,

MY last year's remarks on water purification have led to numerous inquiries for more detailed information, and the whole subject is, therefore, being investigated.

STEAM PIPE EXPLOSIONS.—My remarks on steam pipe explosions led to the matter being treated mathematically and experimentally before the Manchester Literary and Philosophical Society (Vol. xlvi. No. 3), and the experiments were subsequently repeated at the Royal Society, at the Institute of Civil Engineers, at the Manchester Association of Engineers, and at our last annual meeting. In these experiments a glass tube of about ¾in. bore is bent to an L shape, the vertical length being about 6in. to 9in. high, and the horizontal length about 3ft. long, an indiarubber stopper, with a drain pipe, is inserted at the end of this length, and a small drain pipe is also attached just under the vertical leg. This drain is used in preference to the other one, as it removes the hot water which accumulates in the vertical leg. This leg is closed by an indiarubber stopper and a glass pipe with a small Bunsen safety valve.* The pipe is extended to a large flask in which water is made to boil violently until there is a large escape of steam at the safety valve. Water is then drained out of the L pipe, and as soon as its level sinks below the top of the horizontal length, violent water concussions will be noticed, which would shatter the glass tube if the drain pipes were not of indiarubber, and if—but this is unusual—no air bubbles were to form in the pipe. The action may be explained as follows: As long as the water stands in the vertical part of the L pipe, only its upper surface is in contact with steam, and this part gets quite hot; by draining away this water below the upper level of the horizontal pipe, the steam has access to the cold water at the back end of this pipe, very rapid condensation takes place, so rapid, indeed, that generally the safety valve ceases blowing for a time. In spite of this great velocity the cold water seems to be drawn towards the inlet end, but, being rapidly heated, the steam which sweeps over this part raises a wave, which either partly or entirely chokes the pipe, and the steam in the flask has no access to the cold water; a vacuum is instantly formed on the one side of the wave or plug, and with the steam pressure on the other side, this plug is propelled along the horizontal length with such

*NOTE.—A small indiarubber tube, with one longitudinal slit of about ¼in. length.

velocity that if the connections were not elastic the glass pipe would be shattered.

On account of the rapid heating of the water these blows grow weaker and weaker, and interfere with the experiments, so that the water has to be renewed. As this was found to be a rather tedious labour, the horizontal length of pipe was surrounded by a water jacket, which kept the inner water cool, and under these conditions the hammering was continuous. In this modified form the apparatus is suitable for demonstration purposes in a lecture-room.

Grease in Boilers.—It is well known that one of the worst enemies to a boiler is grease, yet the nature of its action is a mystery, and in the hope of eliciting some plausible explanation I brought the matter before the Institution of Naval Architects.* I firstly pointed out that even in clean boilers exceptional strains and stresses can be produced if the fires are maintained at their highest possible intensity of, say, 4,000° Fah. Under these conditions an ordinary cylindrical furnace of 40in. diameter will tend to grow oval, by flattening, to such an extent that the horizontal diameter would be 2in. greater than the vertical one. Similarly, a fire of maximum intensity surrounding a water tube would expand the outside more than the inside, and with thick metal the stresses would be very severe. On the other hand, pipes made of thin metal would be too weak for the steam pressure.

The next point was to show how scale seemed to produce bulges and collapses. Its action is not quite so simple as it seems. Although scale is about 100 times worse than iron or steel as a heat transmitter, it does not seem to do any harm when it is $\frac{1}{10}$in. thick, provided that it adheres to the plate, which may then be considered to be of metal 10in. thick. With increasing thickness and increasing rigidity scale separates from the plate, and the intervening space will soon convert the steam found there into superheated steam, and then the plate rapidly acquires the temperature of the fire, and bulges.

It would therefore suggest itself that if the brittle scale were replaced by a more elastic material, as, for instance, the dense grease which finds its way into a boiler, and which would adhere to its plates, then there would be less chance of injury, for although grease may be 10 times worse than scale as a heat conductor, it is never found in thick layers, and is always absent from furnaces or tubes which have bulged, though plentiful in other parts of such a boiler. It is therefore evident that grease does not act in the same way as scale; in fact, the process of bulging is quite different. Thus almost immediately after the appearance of a bulge in a furnace covered with scale, the whole furnace collapses, for its plates are red hot, and its shape is not now circular, and it is therefore very much

* Note.—*Engineering*, 1902, vol. lxxiii., page 458.

weaker than it was when cold; but bulges due to grease are very slow in growing, and can be watched. The only explanation which suggested itself was, that engine grease undergoes some chemical change when in contact with hot boiler plates, that possibly this new substance, like the precipitates of oxalate of lime and of certain other chemicals, have the power of retarding ebullition, and that the total effect of such retardation is violent generation of steam on the heating surfaces, and collapses of bubbles, which have the effect of water blows. Such blows have been noticed in water-tube boilers. It must be admitted that this explanation of collapses due to grease is not very convincing, and, even if correct, it would be desirable to find some way of demonstrating it, but that does not affect the general experience that even the smallest traces of grease in the feed water will sooner or later lead to boiler troubles, more particularly in high-pressure boilers, and therefore, whenever condensed steam is used for feeding boilers, every effort should be made, by the use of separators or filters, to remove all the grease.

The simplest means of testing scale for grease is to lay it on a little sheet of brass or tin plate, and heat this over a non-smoky flame. The presence of grease will make itself felt by a disagreeable smell, and in extreme cases the scale will turn black or even burn.

New Boilers.—As mentioned in the Annual Report, the number of boilers designed by us and inspected during construction is rapidly increasing; this has naturally led to an increasing number of inquiries as to the best types of boiler to be used under a variety of conditions, and the matter has, therefore, been gone into more fully than in my Memorandum of 1899, which remarks were subsequently amplified in a paper recently prepared for the Manchester Branch of the Institution of Electrical Engineers. The majority of boilers are to be found in mills where floor space is ample, coal cheap, and where the load is steady, but any one or all these conditions are sometimes reversed, and, in addition, the cost of transport to Colonies is frequently an important factor which is generally made still more complicated by demand for maximum economy because of the dearness of coal.

None of these matters can be properly dealt with until the question of economy and of boiler performance has been inquired into more thoroughly than seems as yet to have been done, but the subject is one of great complexity, for, on examining the trials summarised in the late Mr. Bryan Donkin's work on the Heat Efficiency of Steam Boilers, it was found that whereas the results obtained by different experimenters on one boiler installation agree fairly well, the results obtained at other installations of exactly the same type of boiler are most erratic and even conflicting.

Thus if we confine ourselves to Lancashire boilers, of which about 150 tests are recorded, we find enormous variations in the efficiency of boilers worked under practically identical conditions. For instance, in two cases of hand-fired Lancashire boilers, No. 7 and No. 57 in Mr. B. Donkin's Book, both burning English coal, the former at the rate of only 13·8lbs. of coal per square foot of grate, against 16·5 in the latter case, and evaporating only 3lbs. of water per square foot of surface, against 5·6lbs., we yet find that the efficiency of the lightly-worked boiler No. 7 is only 53·7 per cent., against 71·6 per cent. in the case of No. 57, the hard-worked boiler. Again, comparing two other tests, No. 12 and No 67, we find the hard-worked boiler to be the more inefficient of the two, the performances being in the ratios of 53·2 and 74·8.

Evidently these anomalies depended either on the experimenters or on the conditions of firing. The recorded trials were, therefore, subjected to a careful analysis, and those in which the experimenters might be considered at fault, or in which their data were incomplete, were rejected. By this means the total number of about 340 boilers of customary types was reduced to a very few, more especially as, when making the calculations, it was found that the data must have been incorrect, some boilers appearing to have received heat from outside instead of losing some by radiation.

Boiler Efficiency.—It very soon became evident that those boilers were the least efficient in which the excess of air was largest. Special attention was, therefore, paid to this point, and it was found that the amount of heating surface, which is generally thought to be the most important factor as regards performance and efficiency of boilers, is, practically speaking, of secondary importance. In other words, a higher efficiency and a better duty can be got out of a small boiler properly worked than out of a large boiler improperly worked.

In order to have a clear understanding on this point, let it be assumed that the fire of a boiler is being worked under theoretically perfect conditions, which means that for every pound of fuel burnt (supposed to be pure carbon) 11·59lbs. of air are consumed; then, of course, the weight of the products of combustion is 12·59lbs. Experiments show that when 1lb. of carbon is burnt the heat generated is 14,540 British thermal units, and as the specific heat of the waste gases is 0·237, we can estimate the excess temperature of the flame over that of the inlet air as follows :—

$$T_0 = \frac{14{,}540}{0{\cdot}237 \,.\, 12{\cdot}59} = 4{,}875^\circ \text{ Fah.}$$

If now we pass these hot gases along the heating surface of a boiler until their temperature is reduced to, say, 487·5° Fah. above that of the atmosphere, it is evident that the boiler has abstracted 90 per

cent. of the heat, and that 10 per cent. are being carried up the chimney.

Experience shows that it is impossible to attain perfect combustion with only 11·59lbs. of air per pound of fuel; 14lbs. seems to be the lower limit, and with badly-worked fires the waste gases may be thirty to forty times the weight of the fuel burnt.

Let us, therefore, assume that instead of 12·59 the waste products weigh twice as much, viz., 25·18lbs., then the flame temperature is reduced from 4,875° Fah. to 2,437° Fah., and if the gases are again cooled down to 487·5° Fah. the efficiency of the boiler will have been reduced from 90 to 80 per cent., and the heat wasted up the chimney will have been increased from 10 to 20 per cent. If, however, the waste gases are passed over exactly the same heating surface as in the first instance, it is evident that on account of the reduced flame temperature less heat will pass through the plates to the water, and instead of leaving the boiler at a temperature of 487·5° Fah., the waste gas will probably have a temperature quite 25 per cent. higher (compare Table II.), which means that, by admitting double the necessary amount of air at the furnace, the heat wasted up the chimney is increased by about 150 per cent., the efficiency is lowered from 90 to 75 per cent., and the duty is similarly reduced.

It is well known that the walls of buildings transmit large volumes of air into our rooms, although there is but a very slight draught up the chimney; it is therefore but natural that all boilers surrounded by brickwork should, through it, receive a large volume of air, particularly as the draught is from ½in. to 1in. Three cases are recorded in Mr. Bryan Donkin's work where this volume was measured, viz., Nos. 15, 16, and 17 of Cornish boilers. As there calculated, the air leakage through the flue walls was about 4, 4, and 3·7lbs. respectively per pound of coal burnt. There are also four cases (Lancashire hand-fired boilers, Nos. 11—14) in which the leakage through the chain holes and brickwork of an economiser were measured, and amounted to 3½, 4, 4·6, and 3½lbs. per pound of coal respectively.

It is evident that the effect of these leakages is not to lower the initial temperature of the flame nor to reduce the duty of the boiler, but only to reduce the temperature of the gases escaping up the chimney while increasing their weight and volume, the heat thus wasted being exactly the same as if no dilution had taken place. But this leakage is in most boiler tests an unknown quantity, and therefore depreciates their scientific value, and has made it very difficult to utilise these trials as one could have wished.

Although the following illustration is not strictly correct as regards numerical values, it may help to demonstrate the bad effect

of admitting an excess of air at the furnaces. Let the fire of a boiler be burning with the theoretically correct amount of air, then the efficiency of the boiler and its duty will be a maximum. By adding, say, double the weight of air at the foot of the chimney, neither the efficiency nor the duty of the boiler is reduced, but the chimney draught is interfered with because the air volume, and therefore its velocity, is increased, while the temperature, and therefore the lifting power, is diminished. Air leakages between boiler and chimney, therefore, interfere only with the draught, but may indirectly reduce the coal consumption. Assume now that the heating surface of the boiler has been sub-divided: the flame and hot gases traversing one-half, and an equal weight of cold air traversing the other half of the heating surface, then clearly the power of the boiler and also the efficiency must be materially reduced, for not only is the heating surface now only half of what it was—which means that the heat in the flame cannot be as fully extracted as with double the heating surface, which again means that the final temperature of the gases is higher than before, and the efficiency of this half boiler is less—but the other half of the boiler which is being traversed by an equal weight of cold air is parting with its heat to the cold air, whereby the duty and efficiency of the boiler are still further reduced. After leaving the boiler, let the wasted gases which have traversed half the boiler mix with the cold air which has been warmed by the other half, then the chimney temperature will be higher than with no excess of air, but the volume of the gases is greater, and so is their resistance in the flues, and therefore, in this case also, the draught is interfered with.

These conditions are not materially altered by sub-dividing the two streams of hot and cold air into innumerable small streams, nor does it matter then whether, as in actual practice, these streams mix. One may, therefore, safely say that the draught is reduced by excess of air; that the efficiency and the duty is not diminished by leakages beyond the boiler, but that the loss up the chimney increases with the amount of air per pound of coal admitted at the grate, while the duty is also reduced by such air admission.

Incomplete Combustion, generally accompanied by smoke production, is also a cause of reduced efficiency. Every pound of carbon incompletely burnt to carbon monoxide produces only 4,340 thermal units, instead of 14,540; and if all the coal were incompletely burnt, the maximum attainable efficiency would be only 30 per cent. of what it should be. In practice the ratio of incompletely to completely burnt carbon rarely exceeds a few per cent, but this loss is somewhat diminished by the more favourable conditions which now exist, due to the volume of the waste gases being reduced, or the heating surface in relation to these gases being increased, which

means that the chimney temperature will also be reduced, resulting in some efficiency. Nor will the chimney draught be interfered with, for, although the temperature is reduced, the volume of the gases and their resistance is also reduced.

It is evident, therefore, that far greater losses can be incurred by bad stoking with excess of air than with too little air, and there is, therefore, no harm in aiming to attain perfect combustion, more particularly as smoke at once reminds one that the combustion is growing too imperfect. This advice does not apply to gas-fired boilers. Gas, being smokeless, would not be visible, though it travelled up the chimney unburnt. Gas firing has, therefore, always to be regulated by analyses of the waste products.

These various matters were kept in view while carrying through the somewhat exhaustive analysis of trials already referred to, only those trials being finally retained which bore no internal evidence of being unreliable. They embrace Lancashire and Cornish boilers, loco. portable boilers, and marine return tubular boilers. To these have been added some Admiralty trials of Belleville water-tube boilers with economisers.

Heat Transmission.—Laboratory experiments seem to indicate that heat transmission is proportional to the square of the difference of temperature between the flame or gases and the water, but this deduction is not confirmed by this analysis, the most concordant results being obtained if we assume that the heat transmission (C_1) is proportional either to the difference of temperature, or that this heat transmission (C_2) is proportional to the two-thirds power of this difference. The latter assumption does not, however, give such good agreements as the former in those cases where boilers have been tried under very different conditions.

Adopting alternately these two assumptions, co-efficients (C_1, C_2) of heat transmission for the various types of boilers were obtained, and these are detailed in the following table :—

TABLE I.

Co-efficients of Heat Transmission.

B.T.U. transmitted per hour per square foot per 1° Fah. difference on either side of plate.

Type of Boiler or Condition.	C_1	C_2
Water on both sides (condensers)	500 to 600	..
Marine boilers	5·55	·322
Loco. portable boilers	5·21	·251
Lancashire and Cornish boilers	5·05	·251
Water-tube (Belleville, with economisers)	5·26	·225
Economisers	2·79	·141

Let T_o be the initial temperature of the flame in excess of the temperature of the steam, and let T be the excess temperature of the flame or hot waste gases after they have traversed $H\ S$ square feet of heating surface, then, in the first case we have

$$\text{log. } T_o - \text{log. } T = C_1.\ 1{\cdot}84\frac{H\ S}{Q}$$

In the second case

$$\frac{1}{\sqrt{T}} - \frac{1}{\sqrt{T_o}} = C_2.\ 1{\cdot}91\ \frac{HS}{Q}$$

The efficiency is found by subtracting T from T_o and dividing by the sum of T_o and T_s, the latter being the excess of the steam temperature over that of the atmosphere, then

$$\text{Efficiency is } \frac{T_o - T}{T_o + T_s}$$

From the efficiency thus found the losses due to radiation have still to be deducted. If these are known for any type of boiler we can determine its probable efficiency for any condition of firing. The weight of fuel being known, the gas analysis (a very simple operation) at once tells one the weight of waste gases as compared with the fuel, and then, of course, Q, the total weight of waste gases, is known, and comparing this with HS, the heating surface, we can find T, the final temperature. The relative weight of fuel q, to waste gases Q, also tells one what is the initial temperature $T_o + T_s$ of the flame.

We have approximately

$$T_o + T_s = 60{,}000\ \frac{q}{Q}$$

On referring to the Table I. it will be noticed that the co-efficients of heat transmission do not vary materially for the different types of boilers, the marine boiler, however, heading the list. This might be expected on account of the reversal of the flame and the thinness of the smoke tubes ; but from the qualifying remarks given above it is evident that heat transmission and boiler efficiency are not synonymous, the controlling factors being, firstly, the amount of excess air admitted to the furnaces, and, secondly, the radiating surface of the boiler.

Let us deal firstly with the air used for combustion. As already mentioned, deficient air supply is the cause of incomplete combustion and smoke production, and is, therefore, disadvantageous, whereas excessive air admission cools the furnace gases to such an extent that the heat transmission is materially reduced. The most economically-worked boilers are those in which the sum of these two losses is reduced to a minimum. This point is not easy to find in practice, and a rough idea of the complexity of the whole subject will be obtained by glancing at the following table. It is based on the first (the logarithmic) formula just given :—

TABLE II.

Ratio of waste gases and fuel $\frac{Q}{q}$		6·8	16	21	26	31	41
Estimated flame temperature, $T_o + T_s$ °Fah.		2,350	4,130	2,920	2,350	1,970	1,490
Estimated excess temperature, T_o... °Fah. T_s being assumed to be 300° Fah.		2,050	3,830	2,620	2,050	1,670	1,190
Estimated final excess temperatures, T.							
Square feet of heating surface per pound of fuel burnt per hour	$\frac{HS}{q}=\frac{1}{4}$	942	2,750	2,041	1,671	1,411	1,050
	,, $\frac{1}{2}$	431	1,981	1,581	1,361	1,191	920
	,, 1	98	1,019	955	908	843	711
	,, 2	4	271	348	402	426	424
	,, 4	0	16	46	79	108	151
Estimated final temperature, $T + T_s = T + 300$.							
Square feet of heating surface per pound of fuel burnt per hour	$\frac{HS}{q}=\frac{1}{4}$	1,242	3,050	2,341	1,971	1,711	1,350
	,, $\frac{1}{2}$	731	2,281	1,881	1,661	1,491	1,220
	,, 1	398	1,319	1,255	1,208	1,143	1,011
	,, 2	304	571	648	702	726	724
	,, 4	300	316	346	739	408	451
Estimated percentage of heat wasted up chimney, $\frac{T + 300}{T_o + 300}$ 100							
Square feet of heating surface per pound of fuel burnt per hour	$\frac{HS}{q}=\frac{1}{4}$	85·9	73·8	80·2	83·8	86·8	90·5
	,, $\frac{1}{2}$	79·4	55·2	64·4	70·6	75·6	81·8
	,, 1	75·2	31·9	43·0	51·4	53·0	67·8
	,, 2	74·1	13·8	22·0	29·9	36·8	48·6
	,, 4	74·0	7·7	10·8	16·1	20·7	30·2
Efficiency of Heating Surface. **Estimated percentage of heat passing into the water, 100 $\left(1 - \frac{T+300}{T_o+300}\right)$**							
Square feet of heating surface per pound of fuel burnt per hour	$\frac{HS}{q}=\frac{1}{4}$	14·1	26·2	19·8	16·2	13·2	9·5
	,, $\frac{1}{2}$	20·6	44·8	35·6	29·4	24·4	18·2
	,, 1	24·8	68·1	57·0	48·6	47·0	32·2
	,, 2	25·9	86·2	77·8	70·1	63·2	51·4
	,, 4	26·0	92·3	89·2	83·9	79·3	69·8

The top line contains the ratio $\frac{Q}{q}$ of waste gases per pound of carbon burnt. The first value 6·8 represents absolutely incomplete combustion, such as takes place in blast furnaces, and results in the production of a combustible gas: carbonic oxide. Perfect combustion is attained when $\frac{Q}{q}$ is about $12\frac{1}{2}$, but in practice this never occurs without a large admixture of carbonic oxide. A ratio of 16 to 1 is possible with the best conditions of combustion, 21 to 1 is a fairly good practice, 31 is sometimes reached when much air is admitted to reduce the smoke nuisance, and 41 is downright bad practice. Having assumed these various ratios of waste products to fuel, we can easily estimate the initial temperature of the flame. This is given in the second line. The third line contains this same temperature less the steam or boiler temperature, which is assumed

to be 300° Fah. above the ordinary temperature of the atmosphere, and corresponds to a steam pressure of about 160lbs.

The next six lines contain the final temperatures of the gases after passing a certain number of square feet of heating surface per pound of carbon burnt per hour, and headed $\frac{H\ S}{q}$. The next sub-division of this table is arranged on the same plan, but contains not the excess temperatures over the steam, but the excess temperatures over those of the surroundings, say 60° Fah. The values against the ratio $\frac{H\ S}{q} = \frac{1}{4}$ may be taken to represent the temperatures with which the waste gases of a not overworked marine boiler enter the smoke tubes. The values in the line marked $\frac{H\ S}{q} = 1$ represent the temperatures of the waste gases leaving the flue tubes of Lancashire boilers. The next line may be taken to represent the temperatures of waste gases leaving an ordinary boiler in which the heating surface is, say, 30 times the grate surface, and in which 15lbs. of fuel are burnt per square foot per hour. The line marked $\frac{H\ S}{q} = 4$ represents a very lightly-worked boiler.

If we divide the above-mentioned temperatures of the waste gases by the estimated initial temperatures of the flames we at once find the percentage of heat carried up the chimney, and deducting this from 100 we get the next sub-division of the table headed efficiency of heating surface. Here we see that in a marine boiler the furnace and combustion chamber abstract from 13 to 26 per cent. of the heat in the flame. Before the gases enter the tubes these abstract from $63{\cdot}2 - 13{\cdot}2 = 50$ to $86{\cdot}2 - 26{\cdot}2 = 60$ per cent. Before the gases are passed up the chimney, the flue tubes of Lancashire boilers abstract from 47 to 68 per cent. of the available heat, leaving only 16 to 18 per cent. to be absorbed by the shell plates.

The Real Efficiency of a Boiler, not that of its heating surface, is found by subtracting the external radiation from the efficiencies just formed, but we are met by the difficulty of not knowing what this radiation is. Trials and experiences support the view that under ordinary working conditions radiation amounts to from 5 to 10 per cent. If we work a boiler only at half of its power the amount of radiation will be still the same, for the steam temperature is not altered, but the ratio of loss by radiation to heat put into the boiler is doubled. On the other hand, if a

boiler is overworked, resulting, of course, in inefficiency of the heating surface, the relative loss by radiation is very much reduced.

We may look on the matter in another light. The tail-end heating surface of a boiler extracts relatively little heat, therefore a limit of size of boiler may easily be reached where every additional square foot of heating surface abstracts less heat from the flue gases than is radiated by the additional external boiler surface, and that, even neglecting the extra cost of very large or of underworked boilers, they may prove to be less economical than the more heavily-worked ones.

Double Combustion.—Another lesson to be learnt from Table II. is that the heat passing through the furnace plates is so excessive under the best conditions of firing to which they are subjected, that they may give trouble, more particularly if the water is greasy or sedimentary. This danger can be obviated either by excessive or deficient air admission. Excessive air (as already shown) is very wasteful, whereas firing with deficient air supply can be made to give economic results if the imperfectly-burnt waste products are reignited after they have lost a large portion of their heat. This is the plan adopted in the Admiralty type of Belleville boiler, and is the principle of the "split bridge" and similar devices, but, unfortunately, the idea is not carried out as effectively as it should be, and is often the cause of much waste of fuel.

The initial flame temperature with incomplete combustion (see Table II.) is 2,350° Fah. higher than that of the atmosphere, as against 4,130° Fah. excess for complete combustion, and, according to the table, the furnace end of the boiler as far as $\frac{H S}{Q} = \frac{1}{4}$ absorbed respectively 14·1 and 26·2 per cent. of the heat in the fuel. On account of their small volume (6·8 times the weight of the fuel) the imperfectly-burnt gases reduce their temperature to 731° Fah. over the atmosphere after passing ½ sq. ft. of heating surface per pound of fuel burnt per hour. (See Table II.) Here these gases can be reignited, when their temperature will rise 1,500° to 1,800° Fah., so that by this means the maximum temperature to which the boiler heating surface would be exposed is only, say, 2,300° to 2,600° Fah., instead of 4,130° Fah. This is a matter of the utmost importance in scaly or greasy boilers, and deserving of the most serious attention by engineers.

In order that this second combustion may be as perfect as possible, it should take place where there is incandescent brickwork.

The first, or incomplete combustion, should be as incomplete as possible, which means thick fires, with, if necessary, an air blast or an air and steam blast, with no air admission above the bars, in fact, the first furnace should be a gas producer inside the boiler. The second condition follows quite naturally; it is that the second or gas combustion should have its air supply most carefully regulated. These two conditions do not appear to have been carried out together, but they are not unattainable in Lancashire boilers. They are unattainable in locomotives and in most water-tube boilers; they seem to be the most natural working conditions for dry back boilers on account of their white hot combustion chambers, and double combustion might also be carried out in marine boilers, but only if the combustion chambers are made larger than is now customary.

If this change is made in an efficiently worked boiler, with the object of reducing the flame temperature from, say, 4,200° Fah. to 2,300° Fah., it is evident that to transmit, say, 92·3 per cent. (see Table II.) of the fuel heat to the water, one would require $4\frac{1}{2}$ sq. ft. instead of 4 sq. ft. per pound of fuel burnt per hour—a not very serious increase. If, however, the air admission is rather high, say, $\frac{Q}{q} = 26$, and it is wished to reduce this without increasing the temperature above the 2,350° Fah., excess temperature, then, under these wasteful conditions, which lead to a comparatively low heating surface efficiency of only 83·9 per cent. for 4 sq. ft. of heating surface per pound of fuel per hour, by resorting to double combustion, the same efficiency is obtained with a much smaller boiler, $\frac{1}{2}$ sq. ft. being required for the cooling of the gases first formed, and about $1\frac{3}{4}$ sq. ft. for the second combustion, making a total of $2\frac{1}{4}$ sq ft. as against 4 sq. ft. If the same boiler, having 4 sq. ft. of heating surface per pound of fuel is retained, then there should be a gain of about 8 per cent, efficiency.

Overworked Boilers are generally also badly worked, and it is no exaggeration to say that both the efficiency and the power of an overworked boiler can be increased if the conditions of combustion are improved. Unfortunately those conditions are not always attainable in old boilers, which are generally cramped as regards furnaces.

Perfect combustion, combined with smokelessness, can, it seems, be attained even without excessive air supply, but not without intensely high furnace temperatures, by feeding the fuel from under

the fire. The idea is an old one, but until recently seems to have been carried out in a rather clumsy manner. According to the latest arrangements, the fuel is introduced in a trough in the bottom of a furnace, and is forced forwards and upwards. By this means all green coal is always covered with incandescent fuel, and, with a reasonable air supply, combustion can be made nearly perfect.

Another economic question is the use of economisers and superheaters.

Economisers.—The true principle of an economiser is that of counter currents similar to those in modern air-liquefying machines, the one stream of hot air or waste gases traversing one side of a heating surface in one direction, on the other side of which a stream of cooler air, or, in this case, of water is moving in the opposite direction. If the hourly weights of these two streams are equal the difference of temperature on either side of the heating surface will be the same for every point, and the value of the heating surface being equal must be a maximum. In a boiler the water temperature is uniform, but the waste gases are hotter at the furnace end than at the tail end, and the value of the heating surface is not a maximum. In a boiler with an economiser the counter current principle is carried out in instalments, the boiler dealing with the high temperature, and the economiser utilising the remaining low temperatures. When its surface is large enough one can reduce the temperature of the waste gases below that of the steam, which is, of course, quite impossible in a boiler without an economiser. If we could arrange the economiser on the true counter current principle, *i.e.*, letting the warm waste gases come in contact only with the warm feed water just passing to the boiler, while the escaping cooled waste gases come in contact only with the cool feed where it enters the economiser, one might get efficiencies of 90 per cent. and above. There are, however, structural difficulties in the way of carrying out this idea, while the waste gases, containing, as they do, a large percentage of moisture, cause very serious corrosion if cooled to too low a temperature, as they would be if the counter current principle mentioned above were effectively carried out. In fact, troublesome external corrosion is of frequent occurrence in economisers having too large a surface. This corrosion trouble is much worse when flamy coal is burnt than if one uses Welsh coal or anthracite. The softer coals produce much moisture during combustion, which exists as steam in hot waste gases, but is precipitated as moisture when these are cooled.

Superheaters, about which one hears so much just now, have been the fashion several times before, but have not been able to maintain themselves. Superheated steam is certainly economical in an engine, *i.e.*, an engine requires a less weight of superheated steam than of saturated steam, but if a superheater is fitted to a properly proportioned boiler, that boiler produces less steam than before. This is quite natural. Suppose that the efficiency of a boiler is 80 per cent., then by adding, say, 25 per cent. to the heating surface the efficiency may possibly not be increased at all, or only very slightly. Now, if this added heating surface is used for superheating the steam generated in the boiler, it may abstract, say, 10 per cent. of the heat in the flue gases for this purpose, and the steam production must inevitably be reduced by 10 per cent. from, say, 8lbs. per pound of fuel to 7¼lbs. The 10 per cent. extra heat in the steam reduces the engine losses possibly by 20 per cent., so that there would be a net gain, which is, of course, the main object. Superheated steam being troublesome to deal with in several respects, the question still remains whether this gain is worth attaining.

It has become customary to fit superheaters to water-tube boilers, primarily for removing the moisture, which is not adequately separated in the comparatively small steam spaces of these boilers. These superheaters are now, however, made sufficiently large not only to dry the steam, but also to superheat it.

Inquiries are often made as to the probable gain if steam intended for boiling or heating purposes were to be superheated. The answer is that instead of a gain there is likely to be a slight loss if one takes into account the interest on the superheater, as well as on the more costly steel pipes which must now be used. As already shown, the steam production of a boiler is reduced by adding a superheater, and although the smaller quantity of superheated steam contains just as much heat as the larger quantity of saturated steam, the former, being now more like a perfect gas, will probably not part with its heat so readily as the latter. For these reasons there ought to be an advantage in superheating steam which has to traverse long ranges of pipes, for though, if the reduced heat-losing capacity of superheated steam should be neutralised by its higher temperature, one has the advantage of receiving steam and not water at the distant boiling vat.

Importance of Economy.—The wish of all steam users is to have a boiler which, under normal conditions of working, will give highly economical results, and by normal conditions they mean, that the fires are to be worked by an average fireman with no

one to tell him when he is wasteful, and with no one to explain how to be economical. This is a method of procedure which manufacturers would not tolerate for an instant in any of their producing departments. It is true that boilers cost money and never show a direct profit, and are, as it were, past praying for, but surely their expenditure on fuel amounting to from £200 to £500 or more per annum ought to be carefully looked into and reduced to a minimum. This can only be done if steam users will either take the necessary trouble themselves, or at least employ some man who is capable of deciding whether a boiler is or is not doing its duty, and, if not, he should be capable of showing what is wrong and what should be done. There are many young engineers fresh from college, and possessed of sufficient chemical knowledge to carry out gas analyses, who, even if they have not had much engineering practice, would unquestionably soon reduce the heavy coal bill of some works. Such a young man should measure the flue temperatures and analyse the gases under various firing conditions till he has hit on the one which gives the lowest loss up the chimney. If his gas analyses are not satisfactory, he would have to examine the flues for leakages, and should spend his time in the stokehold till he is satisfied that the fireman or the mechanical stoker are doing not only *their* best, but *the* best. In addition, he should be supplied with a feed meter, and should compare the weight of water evaporated with the coal consumed. Seeing that the efficiency of some boilers exceeds 80 per cent., while that of others is less than 60 per cent., there is every prospect that with care the efficiency of the average boiler can be increased one-sixth, which means that if the present coal bill of an average boiler is £350, it can be reduced to £300 or less. In works with several boilers this saving would easily more than cover a young man's salary.

Choice of Boiler Type.—These remarks apply to existing boiler installations, but for many engineers and steams users, who may be thinking of new boilers, an equally important matter is the choice of a suitable type, and by suitable is meant not only economical as regards coal consumption, but as regards total expenses, including interest on first cost and depreciation, and interest on cost of land and buildings. The boiler must also be suitable for the conditions under which it is intended to be worked.

A rough idea as to the relative capabilities, economy, and floor space of different types of boilers can be gathered from Table III., which gives the dimensions for typical sizes, and in which the last columns give details as to the amount of steam produced per square foot of floor space, and the rates of evaporation on which this estimate is based.

TABLE

COMPARISON OF BOILERS AS REGARDS

TYPE.	Boiler Dimensions				Furnaces			Coal Consumption per hour at 20lbs. per sq. ft.	A Boilers surrounded by Flues				
									Dimensions over Brickwork, 9ft. Stokehold and Valves 4ft. high				Water evaporated per hour
	Diam.		Length		No.	Total Width	L'n'th.		Width	Length	Height above floor	Total floor space	
	ft.	in.	ft.	in.		feet	feet	lbs.	ft. in.	ft. in.	ft. in.	sq. ft.	lbs.
Vertical	3	0	7	0	1	$2\frac{2}{3}$	dia.	80[1]	...	...	...	...	...
Cylindrical	6	0	15	0	1	5	dia.	400	...	...	...	...	...
Cornish.....	5	0	25	0	1	$2\frac{1}{2}$	5	250	8 2	34 0	9 9	278	1880
	6	0	28	0	1	3	6	360	9 2	37 0	10 9	340	2700
Lancashire	6	6	28	0	2	5	5	500	9 8	37 0	11 3	358	3700
	7	6	30	0	2	6	6	720	10 8	39 0	12 3	417	5400
	9	0	30	0	2	7	6	840	12 2	39 0	13 9	475	6300
Lancashire Tubular	7	6	20	0	2	6	6	720	10 8	37 0[3]	12 3	395	5800
	9	0	20	0	2	7	6	840	12 2	37 0[3]	13 9	450	6700
Dry Back Return Tubular	9	9	9	6	2	6	6	720	12 11	24 6	14 1	317	5800
	11	0	8	9	2	7	6	840	14 2	23 9	15 4	337	6700
Marine Return Tubular	11	0[0]	9	3[0]	2	6	6	720	...	...	...	...	...
	12	0	9	8	2	7	6	840	...	...	...	...	...
	13	0	10	0	3	9	6	1080	...	...	...	...	...
	14	6	9	9	3	$10\frac{1}{2}$	6	1260	...	...	...	...	...
Locomotive	2	9	9	6	1	$2\frac{1}{2}$	$2\frac{3}{4}$	110[1]	...	...	...	...	...
	5	0	13	6	1	$4\frac{1}{3}$	6	520	...	...	...	...	...
	Width												
Babcock and Wilcox Water-tube Boilers	3	3	19	0	1	$3\frac{1}{4}$	5	325	8 3[2]	28 0	16 0	231	2430
	5	0	23	0	1	5	6	600	10 0[2]	32 0	18 0	320	4500
	8	6	23	0	1	$8\frac{1}{2}$	6	1020	13 6[2]	32 0	18 0	432	7650

0. These are the dimensions of the largest marine boiler that can be sent by rail.
1. Burning 15lbs. per square foot of grate.
2. This width includes one 2ft. side passage for tube sweeping purposes.
3. This length includes 6ft. at end of boiler for tube sweeping purposes.
4. This width includes one 2ft. side passage and half of an 18in. division wall for two boilers.
5. This length includes only a 6ft. stokehold and 6in. space at boiler back.
6. This length includes 10ft. stokehold instead of 9ft., on account of overhanging smoke-box.

III.

EVAPORATION PER SPACE OCCUPIED.

B Boilers lagged.								C Economiser.									
Dimensions over lagging, and 6in. clearance for inspection, 9ft. stoke-hold, and valves 4ft. high.							Water evaporated per hour.	Dimensions over brickwork and pit.			Total Water evaporated per hour.	Estimated steam production per sq. ft. of floor space.			Assumed steam production per pound of fuel.		
Width		Length		Height above floor		Total floor space		No. of Pipes.	Floor space Econ.	Floor space A.& C.		A	B	A.& C.	A	B	A. & C.
ft.	in.	ft.	in.	ft.	in.	sq. ft	lbs.		sq. ft.	sq. ft	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
4	8	9	9^5	11	0	46	400	...	...	...	...	...	8·7	...	...	5	...
8	0	12	9^5	19	0	102	2000	...	...	...	...	...	19·5	...	...	5	...
The Boilers are not set without Side Flues.								...	...	...	...	6·9	...	...	$7\frac{1}{2}$	...	...
								...	...	...	...	7·9	...	...	$7\frac{1}{2}$	...	...
Ditto.								64	70	428	4200	10·6	...	9·8	$7\frac{1}{2}$	...	$8\frac{1}{2}$
Ditto.								96	100	517	6100	12·9	...	11·8	$7\frac{1}{2}$	...	$8\frac{1}{2}$
Ditto.								128	125	600	7100	13·4	...	11·8	$7\frac{1}{2}$	...	$8\frac{1}{2}$
9	3	37	0^3	12	3	342	5400	...	...	...	...	14·7	15·8	...	8	$7\frac{1}{2}$	...
10	9	37	0^3	13	9	393	6300	...	...	...	...	14·9	15·8	...	8	$7\frac{1}{2}$	...
11	6	24	6^6	14	1	282	5400	...	...	...	...	18·3	19·1	...	8	$7\frac{1}{2}$	...
12	9	23	9^6	15	4	303	6300	...	...	...	...	19·9	20·8	...	8	$7\frac{1}{2}$	...
12	9	19	7^6	15	4	250	5800	...	...	...	...	...	23·2	...	...	8	...
13	9	20	0^6	16	4	275	6700	...	...	...	...	...	24·3	...	...	8	...
14	9	20	4^6	17	4	300	8700	...	...	...	...	...	29·0	...	...	8	...
16	3	20	1^6	18	10	326	10000	...	...	...	...	...	30·6	...	...	8	...
4	5	24	6^3	9	3	108	880	...	...	...	...	...	8·1	...	...	8	...
6	8	28	6^3	11	6	190	3900	...	...	...	...	...	20·5	...	...	8	...
No side flues, but two boilers placed side by side.													2 b'l'rs side by side				
7	6^4	28	0	16	0	210	2430	...	...	...	...	10·5	11·6	...	$7\frac{1}{2}$	...	...
9	3^4	32	0	18	0	296	4500	96	54	374	4800	14·1	15·2	11·8	$7\frac{1}{2}$	...	8
12	9^4	32	0	18	0	408	7650	48	70	533	8170	17·5	18·8	15·3	$7\frac{1}{2}$	...	8

Under favourable conditions, such as exist at boiler trials, one may expect an efficiency of, say, 80 per cent. as a maximum with boilers provided with economisers, and deducting 10 per cent. where these are missing, one should not expect more than 70 per cent. in the boilers alone unless their duty is materially reduced, so as to give a large heating surface per pound of water evaporated. These remarks apply to Lancashire and water-tube boilers. Marine and other smoke-tube boilers, with their very efficient heating surface, may be credited with an efficiency of 75 per cent., which it would not pay to raise to 80 per cent. by an additional economiser. In round figures, one may say that 70 per cent. represents 7lbs. of water evaporated to high-pressure steam when burning ordinary fuel, 75 per cent. is represented by 7½lbs., and 80 per cent. by 8lbs. These are the values adopted in Table III. Of course, the evaporations are reduced if the boilers are badly designed, the furnaces small, and if the stoking is bad.

Experience shows that with good chimney draught good economic results are obtained when burning about 15lbs. of English or Scotch coal per hour per square foot of grate, and about 12lbs. of Welsh. With skilled stokers good results are still obtained when respectively 20lbs. and 16lbs. are burnt, but with 25lbs. and 20lbs. good results cannot be relied on without forced draught, and then only with large furnaces, when probably 35lbs. and 30lbs. can be burnt. Mechanical stokers without forced draught may do well when consuming up to 30lbs. per square foot (or with forced draught up to 60lbs.), but then the grates are reduced from 6ft. to about 3ft. or 4ft. Generally speaking, the coal consumption per foot of furnace diameter is from 100lbs. for small furnaces to 120lbs. for large ones, either with hand and machine firing. With forced draught these quantities can be increased to about 150lbs. and 200lbs., but uneconomic results are likely to be obtained. Multiplying these figures into the furnace diameters of various boilers, and into their rates of evaporation, one arrives at the quantity of steam produced per hour.

The dimensions of locomotive boiler grates being limited, one may assume the coal consumption to be at the rate of about 20lbs. per square foot per hour. The grates of water-tube boilers on land are only limited as regards their widths, which do not exceed the boiler widths, but here, too, it is unusual to make the firebars longer than 6ft., so that with these boilers, too, their power varies as their widths, a consumption of 120lbs. per lineal foot per hour being a fair working quantity.

Glancing down the last columns of Table II. we find that, as might be expected, small boilers occupy relatively more space than large ones. A 5ft. Cornish boiler heads the list, producing only 6·9lbs. of steam per square foot of floor space; but a small locomotive boiler, a small

vertical boiler, and a small Lancashire boiler are nearly as wasteful of floor space; the vertical type may also be credited with being most uneconomical.

Glancing at the Lancashire and water-tube boilers, we find that we have to deal with a question of floor space *versus* economy, either type producing from 2lbs. to 3lbs. less steam per square foot of floor space if economisers are used than without, while the economy is increased 6 to 12 per cent. Where land is available, economisers are therefore advantageous, but where the cost of space is prohibitive, they may be out of place, and then, of course, it is a question of selecting the boiler which will be most economical without an economiser, and occupy the least possible space. Here the marine type is unquestionably the most advantageous, even the smallest on the list capable of evaporating, say, 5,800lbs. to 6,700lbs. of water per hour, occupying less than one-half the floor space of a Lancashire boiler and economiser of 6,300 evaporative power, and only about three-quarters of the floor space required by a water-tube boiler of the same power. Where the means of transport permit of large marine boilers being placed in position, these are certainly the most advantageous as regards floor space required, and therefore, doubtless, cheapest where land is dear. Marine boilers larger than 11ft. 0in. × by 9ft. 3in. over all cannot be sent by rail.

Manufacturers and their engineers have, as a rule, been brought up to look on the Cornish and Lancashire boiler as the best, a view which is not shared to the same extent on the Continent, but which is supported by the experience that these boilers are fairly economic, that they are absolutely safe if looked after, easily cleaned, and ready to respond to sudden demands for extra steam.

Marine engineers consider their return tubular boiler to be superior to all others: it is economical without the addition of an economiser; they think it as safe as a land boiler, for, in spite of diameters of 18ft. and pressures of 200lbs., no shell burst has been recorded amongst many thousand boilers afloat. They are easily cleaned and inspected, and, as proved by sudden racing of the engines in heavy seas, these boilers also respond readily to unexpected excessive demands.

College-trained engineers have a very natural liking for the water-tube type, for, in the lecture room, its various features lend themselves very readily to praises; such, for instance, as that small tubes must be safer than large boiler shells, that small water volumes can do less harm in case of explosions than large ones in other boiler types, and also that one can raise steam more rapidly with small water volumes than with large ones; one can also urge that water tubes should be more efficient than smoke tubes, as the flames cross them and get broken up, and also that defective tubes can be more readily renewed than large shell plates can be repaired, &c.

We thus see the Lancashire boiler used almost exclusively in factories, the return tubular boiler at sea, and the water-tube boiler in electric light stations, but to an outsider these very marked divisions might not appear to be quite justifiable, and there seem to be circumstances under which one boiler type might with advantage replace another. These conditions will be more readily understood if the capabilities and varied duties of boilers are briefly reviewed.

We have now to consider the conditions under which boilers are worked.

I. Continuous Work. The marine conditions are in a way the simplest. Fires are lit at the commencement of a voyage, which may last weeks, the water is only taken from the condenser and is always the same, the coal is usually of the best quality, so that fires need only be cleaned once in 24 hours, and the smoke tubes are swept once or twice a week. Continuous working of boilers, but accompanied by sedimentary water and impure fuel, is the practice in flour mills and many chemical works, including those where the smelting of ores is carried on. In some works, more particularly in electric light stations, a few boilers are also always at work.

II. Less continuous working occurs in factories, more especially in spinning and weaving mills. The boilers work all day but rest at night and on Sundays. The fires are cleaned during meal hours and banked overnight. The water is generally sedimentary and the fuel of a poor quality. Heat is required overnight to warm the factories.

III. In some works the loads are very irregular, thus in dyeworks and laundries much steam is required at odd periods during the day or week. In Bessemer steel works the main engines work full power for from 10 to 20 minutes, and then rest for a considerable time. Winding engines require full steam more frequently.

IV. In electric light stations the load is more irregular and uncertain. Full power demands recur every evening, but are also made quite unexpectedly in cases of sudden fogs. There is no escape from these calls, and it is doubtful whether these conditions are not even severer than those under which battle-ships are expected to labour in time of war, for although if taken unawares by an enemy, demands for steam may be very pressing, the engines will not work at full power until the steam supply is sufficient, whereas electric engines automatically increase their exertions, and draw more and more steam from the boilers as the lights in the town are turned on.

I. The conditions of CONTINUOUS WORKING are fairly simple and require no further remarks.

II. DAY WORK for land boilers is one of the most common practices, and in this country boilers with large water volumes are favourites, as they store up just about enough heat to keep the factory warm overnight without requiring an attendant to look after the fires, which are, of course, banked. The cooling down of the boilers under these conditions cannot therefore be counted a loss. It would be uneconomical to light fires and get up steam anew every morning.

III. and IV. IRREGULAR WORKING, as in electric light stations. Here, of course, the loss of heat when the boilers are standing idle is a dead loss, and it is only by experimenting that one can decide whether it is cheaper to bank fires or to get up steam for each occasion. The best type of boiler for these conditions is also not yet definitely settled. If we use Lancashire boilers, their fires must be banked, for it seems impossible to raise steam with sufficient rapidity from the cold condition. If we use water-tube boilers, it is practically impossible to bank fires and to maintain steam; or, rather, with banked fires they require an attendant to watch them as well as the water level, for, with a slight access of air, combustion may suddenly be started, and the water in the boiler evaporated. If the periods of hard steaming are known beforehand, the fireman can, especially with a water-tube boiler, keep his fires thick and well burnt through, and can then increase the draught as soon as the extra power is required; but if the attendant is taken unawares, if the fires are nearly burnt out, or perhaps banked when steam is wanted, the first effect of adding green coal will be to lower the pressure, for there is no large water reserve in these boilers, and under such fitful conditions boilers with large water volumes are more advantageous than water-tube boilers.

Water-tube boilers can also store power, but in a very undesirable form. The matter was very forcibly brought to my notice quite recently. A water-tube boiler had been worked at full power for several hours. The firing was then stopped suddenly, but the feed supply had to be continued for another five hours, because the boiler was blowing off steam all this time. What happened was this: while raising steam, and during, say, the first four hours, an enormous quantity of heat had to be poured into the brickwork, during the next four or five hours the brickwork had acquired its highest temperature and the boiler was doing its best, the only losses being up the chimney and by radiation. Then, when the demand for steam suddenly ceased, the reserve heat in the brickwork reappeared in a most objectionable manner. Had the steam demand been a limited and steady one, this feature of the boiler would have been

less conspicuous. The fires would have had to be forced to their utmost extent during the first four hours, not only for steam production, but also for heating the brickwork. A time would then come when the firing would have had to be reduced to its normal condition, the flames would be less hot, and at the end of the day their heat would be largely supplemented by the heat previously stored up in the brickwork, which would be growing colder, and there would be no serious inconvenience after working hours. In the case under consideration the fuel supply and not the steam demand was kept steady.

Boiler Trials.—This single experience suffices to convince one that trials of water-tube boilers, having much brickwork, have to be scrutinised most carefully before one can express an opinion on their performances, and to carry out trials on these boilers in the same way as many trials on Lancashire and marine boilers are carried out, may be a valueless proceeding. The conductors of such trials have generally aimed at obtaining one or more sets of initial readings under exactly the same conditions under which the final reading or sets of readings are to be obtained. Thus, if the boiler has been working full power since, say, 6 a.m., starting with clean fires, the feed and coal measuring would commence at, say, 8 a.m. During the dinner hour the fires would be cleaned again, and two hours later the trial would end, care being taken that the steam pressure and water level height shall be the same as at 8 a.m., both readings of the gauge glass being taken with a falling water level, because then the temperature of the boiler water is likely to be uniform. Of course, the accuracy of such a trial is doubled, trebled, &c., if both at the commencement and end of the trial additional readings are taken, say, every quarter of an hour, or, more conveniently, every time that the stokehold floor is clean and new fuel has been weighed out. These check readings at the commencement and end of the trial may with advantage be carried on for two or more hours. With trials of water-tube boilers set in brickwork these check readings must be continued throughout the day, and curves drawn to represent the coal consumption and evaporation, the relative rates at different times of the day would then represent variations of efficiency, and this, as has already been suggested, will be practically valueless unless the rate of firing is kept constant regardless of steam production, so as to insure a uniform temperature of the brickwork.

Trials on both types of boilers can also be carried out on the principle of weighing all the coal that goes into the boiler, drawing the fires at the end of the trial, weighing ashes and analysing them, and making allowances, as well as one can, for the surplus heat in the water and in the brickwork, the object of such trials would be not to determine the boiler efficiency while working

steadily, but to determine the total cost of a day's steam production; but for this purpose there is really no more perfect plan than to have a 24 hours' trial. Naturally, if such a prolonged trial is undertaken, one may as well make detailed observations so as to be able to draw up a complete balance-sheet, showing cost of fire lighting and raising steam, steam production and warming of brickwork, chimney losses and losses by radiation, fuel waste due to drawing fires, cost of banking fires, and radiation when standing idle. Such trials would be of value not only scientifically, but also practically, from a steam user's point of view.

Radiation. These remarks should indicate sufficiently clearly that the determination of the actual radiation and similar losses is not an easy matter, and that probably a theoretical estimate may be of more value than data obtained from trials. The remarks just made may also prepare one for the startling discovery that according to the published trials made by some of the best authorities, radiation amounting to as much as minus 12 per cent. have been recorded. In other words, the observed efficiency of the boiler was so high, and the loss of heat up the chimney was so great, that the sum of the two amounted to as much as 112 per cent. of the heat contained in the fuel! Whether these absurd results are due to incorrect sampling of fuel and gases, wrong readings of the pyrometers, inaccurate estimation of priming, or to those disturbing conditions of brickwork and irregular duties mentioned above is not known,

Numerous trials have been made as to the heat lost by radiation from pipe surfaces, and also on the conductivity of materials, with the help of which one could estimate the heat radiated from boilers; but for some not very evident reasons, practical experience on boiler radiation makes it appear to be twice, or, perhaps, three times higher than these experimental results would warrant. The comparisons now to be made between several types of boilers are, therefore, based on radiation which is assumed to be twice as high as that found experimentally with pipes. These values are given in the second column of Table IV.

TABLE IV.

Heat radiated per square foot of surface per hour per 1° Fah. difference of temperature on either side of radiating thickness.

Material.	Radiation from Pipes. B.T.U.	Value at Adopted Rates of Radiation. B.T.U.
Bare Iron	4·0	...
Iron Plates covered with composition 2in. thick.	0·7	1·4
Iron Plates covered with composition 3in. thick.	0·5	...
Brickwork 12in. thick	0·42	...
Brickwork 18in. thick	0·28	0·56
Brickwork 24in. thick	0·21	...

The heat capacity of brickwork is about one-half of that of water, *i.e.*, it requires about 31 B.T.U. to raise 1 cubic foot of brickwork 1° Fah. To find the heat stored in the outer brickwork of a boiler, find the mean temperature of the flame and gases, and the mean of this mean and the outer temperature, multiply this value by 31 and by the number of cubic feet of brickwork.

Water Tube Boilers. Let us consider the three Babcock and Wilcox boilers mentioned in Table V.

TABLE. V.

	General Dimensions, &c.		
Size of Boilers, exclusive of Brickwork	3′ 3″×19′ 0″	5′ 0″×23′ 6″	8′ 6″×23′ 0″
Thickness of Brickwork .....incl	18	18	18
Volume of Brickwork .....cub. ft	790	1,100	1,240
Area of Steam Drums and Boiler Fronts ..... sq. ft	134	295	430
Heating Surfaces ..... sq. ft	735	1619	2852

Assumed conditions of working: 4 sq. ft. of heating surface per 1lb. fuel burnt per hour. Ratio of waste gases to fuel $\left(\frac{Q}{q}\right)$ as under. When the firing is increased to 1lb. per 2 square feet of heating surface the "hours full work" in the following Table are hardly affected :—

TABLE VI.

Heat stored in side walls of water-tube boilers.

Size of Boiler	3′ 3″ × 19′ 0″		5′ 0″ × 23′ 0″		8′ 6″ × 23′ 0″	
	Evaporative Units	Hours Full Work	Evaporative Units	Hours Full Work	Evaporative Units	Hours Full Work
$Q/q = 16$	9,240	3·40	12,750	4·60	14,360	5·20
$Q/q = 21$	8,190	1·35	11,300	1·87	12,730	2·10
$Q/q = 31$	7,300	0·68	10,110	0·94	11,380	1·05

The values given under the headings "hours full work" mean that when the boiler has settled down to steady work, consuming $\frac{1}{4}$lb. fuel per square foot of heating surface per hour, then the brickwork will hold as much heat as would be produced by firing at the above rate for the hours mentioned; but it does not mean that after drawing the fires the brickwork could produce the full amount of steam for the time, for it must be remembered that the hot brickwork is radiating heat both towards the heating surface of the boiler and externally, that certainly one-half of this heat is lost, and that, as the boiler temperature is assumed to be 300° higher than the outside temperature, only from one-half to two-thirds of the remaining half can

be transmitted to the boiler, and, in addition, there are serious losses by radiation from the boiler drums, &c. Further, this heat is not applied to the more central tubes, and full-power steaming cannot under such conditions be expected. Therefore, although the brickwork does store an enormous quantity of heat, certainly not more than one-sixth, and possibly not one-twelfth, can be made useful. That these values are not at all imaginary is shown by the above-mentioned experience.

The conclusion to be drawn from this inquiry is that bare statements as to the evaporative efficiency of water-tube boilers with heavy brickwork are valueless, for the large heat capacity of this brickwork may, during the trial, be affecting the efficiency either one way or another. Trials on such boilers should be carried on for much longer periods than on ordinary boilers. The rate of firing should be absolutely uniform, a condition which cannot be attained if an engine trial is being run at the same time, and which is at least difficult to attain with hand firing because of the necessity of cleaning fires.

If it is desired to ascertain the daily coal consumption, including lighting fires or banked fires, then, of course, the trial should be carried out under ordinary working conditions, and preferably for 24 hours.

We may now deal with the question of radiation on the assumption that the boiler is being worked at a steady rate, and that the temperatures in the brickwork are not changing.

TABLE VII.

Estimated Heat Losses from Water-tube Boilers.

Dimensions of Boilers.				3′ 3″ × 19′ 6″	5′ 0″ × 23′ 0″	8′ 6″ × 23′ 0″
Estimated radiation from Drums and Fronts			E. U.	58	124	186
Radiation from brickwork.	Ratio Heat Surface / FUEL	Ratio Waste Gases / FUEL				
	2	16	E. U.	630	854	854
	2	21	,,	478	650	650
	2	31	,,	362	490	490
	4	16	,,	598	812	812
	4	21	,,	438	584	584
	4	31	,,	314	426	426
Available Heat.	2	...	,,	5,520	12,150	21,390
	4	...	,,	2,760	6,075	10,696
Total Radiation.	2	16	per cent.	12·5	8·0	4·9
	2	21	,,	9·7	6·4	3·9
	2	31	,,	7·6	5·1	3·2
	4	16	,,	23·8	15·4	9·3
	4	21	,,	18·0	11·8	7·3
	4	31	,,	13·5	9·1	5·7
Total Radiation and loss up chimney.	2	16	per cent.	26·3	21·8	18·7
	2	21	,,	31·7	28·4	25·9
	2	31	,,	44·4	41·9	40·0
	4	16	,,	31·5	23·1	17·0
	4	21	,,	28·8	22·6	18·1
	4	31	,,	34·2	29·8	25·4

These results, although they are only of comparative and not of absolute value, are of interest in several respects. They show that it is far more important to have perfect combustion in an overworked boiler than in a boiler worked under ordinary conditions, and they show that the losses (chiefly up the chimney) are relatively so high that it is doubtless cheaper to pay the interest on the cost of a second boiler than to lose 25·9 per cent. against 18·1 per cent. of the heat in the fuel, the ratio of waste gases to fuel being assumed to be 21.

In MARINE BOILERS the heat losses are more easily estimated, for there is no radiation through the brickwork, and this loss is, therefore, independent of the initial flame temperature and the perfection of the combustion.

The following Table also contains some details as to heat required to raise the water volume to the steaming temperature, and the time during which 30 per cent. reserve power can be developed by stopping the feed and lowering the water level 12in. :—

TABLE VIII.

ESTIMATED HEAT LOSSES, &c., FROM MARINE BOILERS.

Sizes of Boilers				11′ 0″×9′ 3″	12′ 0″×9′ 8″	13′ 0″×10′ 0″	14′ 6″×9′ 9″
Heating Surfaces ..... sq. ft.				1,080	1,260	1,630	1,890
External Surfaces (bare and exclusive of uptake).. sq. ft.				98	113	128	147
Do., Covered, (2″).. sq. ft.				330	385	438	507
Radiation from Bare Surfaces, E.U.				242	280	318	366
Do., Covered Surfaces, ,,				142	168	190	220
Total Radiation ...				384	448	508	586
RATIOS.	Heat Surf. / Fuel.	Waste Gases. / Fuel.					
Available Heat...	2	...	E.U.	8,100	9,440	12,200	14,200
Total Radiation..	2	...	per cent	4·7	4·7	4·2	4·2
Available Heat...	4	...	E.U.	4,050	4,720	6,100	7,100
Total Radiation..	4	...	per cent	9·5	9·5	8·3	8·3
Total Radiation and Loss up Chimney.	2	16	per cent	18·5	18·5	18·0	18·0
	2	21	,,	26·7	26·7	26·2	26·2
	2	31	,,	41·5	41·5	41·0	41·0
	4	16	,,	17·2	17·2	16·0	16·0
	4	21	,,	20·3	20·3	19·1	19·1
	4	31	,,	30·2	30·2	29·0	29·0
Weight of Water in Boilers, tons				11·2	13·9	16·9	20·3
Steam Raising Time.....	2	...	hours	1·04	1·10	1·03	1 07
	4	...	,,	2·08	2·20	2·06	2 14
Weight of Water due to 12 in. difference of level tons				2·1	2·4	2·7	3·0
Time required to lower Water level 12″ when working 30 per cent. extra power	2	...	hours	0·75	0·75	0·65	0·60
	4	...	,,	1·50	1·50	1·30	1·20

Comparing these estimates for those obtained for the water-tube boilers, particularly the 13ft. by 10ft. marine, with the 5ft. by 23ft. water-tube, which two boilers have the same heating surface, it appears that there is a slight economic advantage on the side of the marine boiler under heavy working conditions, and a very considerable advantage under light working conditions. In fact, for the best conditions of combustion the efficiency of the water-tube boiler is decreased with decreasing duty, while that of the marine boiler is increased.

Comparing the periods which it would take to warm up the brickwork or the water (see Tables VI. and VII), we find that the water-tube boiler requires from one to four and a half hours, as against two with the marine boiler. These heats are, of course, dead losses every time the boilers are cooled down again. But this comparison requires an explanation. Marine boilers cannot be got to raise steam in two hours unless they are provided with effective circulating arrangements. Devices based on the difference of density of warm and cold water are not efficient enough, nor do steam jet circulators seem to do as much good as might be expected of the steam they consume. The most effective appliance seems to be a pipe connection from the blow-off to the feed pump, which can be worked when there is only 5lbs. or 6lbs. of steam pressure, but which ought to be worked, at least at first, by an auxiliary boiler. The large quantity of heat estimated to be stored in the brickwork of water-tube boilers is only found there when the boiler has worked for a long period. When steam is being raised quickly, the inner surfaces of the brickwork will acquire a very high temperature, which diffuses only very slowly. If that were not so, these boilers would be slow to raise steam, instead of being quick.

Boilers containing much water are supposed to have much reserve power for sudden demands. This is not quite the case, and a simple calculation would show that a vessel holding 10 tons of water at a pressure of 170lbs. per square inch, and at a temperature of 374° Fah., would evaporate only about 280lbs. of water if the steam pressure were allowed to drop down to 100lbs. pressure. This is only equal to about two minutes' full power steaming of a fairly large marine boiler. On the other hand, boilers having a large water-level area and a considerable range of water level can be worked for reasonably long periods without feed, and will during these periods produce about 30 per cent. extra steam. A boiler evaporating 12,200lbs. per hour (see Table VIII.) could by this means increase its output to 15,860lbs., and if the available water from the top to the bottom of the water gauge glass is, say, 2·7 tons, this extra power could be kept up for about 0·65 hour. This explains the values noted in the table as "30 per cent. extra full power."

Of course, if under easy working conditions the boiler only produces ¼lb. of steam per square foot of heating surface, instead of ½lb., as here assumed, the time during which this power is available would be doubled to 1·30 hour.

When boilers are fitted with economisers the case is somewhat complicated. If we take the boiler and economiser to be one, and if we allow steam to be generated in the economiser, then the case is on all fours with the above. If, however, the feed pumps are only partially closed down, so as to deliver the feed at the same temperature as the steam, then the gain in power is proportional only to the comparatively slight rise of economiser temperature due to the restricted feed.

Dry Back Boilers, with their brick combustion chambers, occupy a position which is intermediate between that of water-tube boilers and marine boilers, and their radiation is partly through the brickwork, and therefore partly proportional to the perfection of combustion; and radiation is partly through the boiler plates, and therefore independent of the furnace efficiency. Some dry back boilers are surrounded by flues, like the Lancashire boilers; on account of these complications it will be more convenient to confine our further attention to the Cornish and Lancashire boilers. On account of the absence of internal-combustion chambers, dry back boilers are cheaper than marine boilers, and for the same powers the diameters may be smaller, thus allowing them to be carried by rail.

Cornish and Lancashire Boilers.—These are surrounded by brickwork, whose temperature is never very high, and, being in juxtaposition to other flues, radiation from this brickwork must be nearly negligible. On account of the low temperature of this brickwork, and because of the large water volume in the boilers, no inconvenience is experienced by generation of unnecessary steam after the fires are drawn or banked. These boilers possess the additional advantage for factories that their large water volumes, when highly heated, represent a useful heat store, which is utilised overnight in warming the factories. With water-tube boilers, and possibly also with marine boilers, the reserve heat in the water is too small to supply the heat lost overnight in factories, and where these boilers are used, one is put to the expense of having a boiler attendant overnight where no night watchman is kept, or else one has to fire up earlier than would otherwise be necessary.

It will be seen that there is not very much difference as regards economy between the largest Lancashire boiler and the corresponding marine boiler, but with economisers the chimney losses can be reduced. Under these circumstances one would naturally rather overwork Cornish and Lancashire boilers, and trust to the economisers for good results. Comparing the smallest water-tube boiler

with the smallest Lancashire or the largest Cornish boiler, we find that these latter types are very much more efficient, particularly if the conditions of combustion are good. The time during which the reserve power of 30 per cent. in these boilers can be utilised is about three times as long as with marine boilers.

TABLE IX.

ESTIMATED HEAT LOSSES, &C., FROM CORNISH AND LANCASHIRE BOILERS.

TYPE OF BOILER.				CORNISH.		LANCASHIRE.		
Size of boiler				5× 25	6′ ×28′	6½′ × 28′	7½′ ×30′	9′ × 30
Heating surface			sq. ft.	430	580	770	1,010	1,170
External surfaces								
Bare front			,,	50	40	44	53	70
Top covered with 2in. composition			,,	150	225	225	270	330
Radiation								
From bare surface			E. U.	76	100	110	132	174
From covered top			,,	66	98	98	118	142
Total			E. U.	142	198	208	250	316
Ratios.	Heat Surf. / Fuel.	Waste Gases. / Fuel.						
Available heat...	2	...	E.U.	3,220	4,340	5,780	7,580	8,780
Total radiation	2	...	per cent.	4·4	4·6	3·6	3·3	3·6
Available heat...	4	...	E.U.	1,610	2,170	2,890	3,790	4,390
Total radiation	4	...	per cent.	8·8	9·1	7·2	6·6	7·2
Total radiation and loss up chimney.	2	16	per cent.	18·2	18·4	17·4	17·1	17·4
	2	21	,,	26·4	26·6	25·6	25·3	25·6
	2	31	,,	41·2	41·4	40·4	40·1	40·4
	4	16	,,	16·5	16·8	14·9	14·3	14·9
	4	21	,,	19·6	19·9	18·0	17·4	18 0
	4	31	,,	29·5	29·8	27·9	27·3	27·9
Weight of water in boilers			tons	6	10	12	17	24
Steam raising...	2	...	hours	1·24	1·73	1·55	1·67	2·04
Time	4	...	hours	2·48	3·46	3·10	3·34	4·08
Weight of water due to 12in. difference of level,			tons.	2·8	3 9	4 1	5·2	6·7
Time required to lower water level 12in. when working 30 per cent. extra power.	2	...	hours	2·5	2 6	2·1	2·0	2·2
	4	...	hours	5·0	5·2	4·1	4·0	4·4

If we compare these comparative results with the performances of boilers detailed in Table III., it will be seen that the heating surface of the water-tube boilers is doing only about one-half the duty of that in marine and Lancashire boilers, and that, therefore, a more direct comparison than has here been attempted cannot easily be made, and we would have to deal with individual cases as they arise somewhat on the following lines :—

COMPARISONS. Let us compare the 5ft. water-tube with the 12ft. marine and the 9ft. Lancashire boilers as regards efficiency when working at reduced power (say $\frac{H\,S}{q} = 4$) for two hours

out of the 24, and maintaining steam under banked fires for the remaining 22 hours. Neglecting the complication introduced by the cooling and reheating of the water-tube brickwork, we have, if the conditions are fairly good (say $\frac{Q}{q} = 21$), the respective efficiencies of 77·4, 79·7, and 82·0 per cent. during two working hours, We also have the respective radiation losses of 11·8, 9·5, and 7·2 per cent. during the remaining 22 hours; then the net efficiency per day works out at 37·3, 43·3, and 50·9 per cent. respectively, which percentages stand in the ratio 6, 7, and 8.

Let us compare these boilers as regards efficiency when working at ordinary power for nine hours once a week, which means, of course, raising steam once a week, and then wasting the heat stored in the brickwork or water. Assume that the raising of steam takes two, six, and twelve hours respectively (though with the necessary circulating appliances steam can be raised in a shorter time in the marine boiler). Assume that the temperatures increase gradually, and that therefore the radiation during the steam-raising period is equal to half the radiation when at work, then we have to supply the water-tube boiler with heat equal to 0·5 + 1·87 + 9 hours' steaming plus radiation for one hour, making a total of 11·5 hours, half an hour's firing being allowed for heating the boiler water. The marine boiler has to be supplied with heat equal to 2·20 + 9 hours' steaming, plus radiation for three hours, making a total of 11·48 hours. The Lancashire boiler has to be supplied with heat equal to 0·5 + 4·08 + 9, plus radiation for six hours, making a total of 14·0 hours, half an hour's firing being allowed for heating the flue walls. With these details the efficiencies of the water-tube, marine, and Lancashire boilers work out at 60·4, 62·4, and 50·8 per cent., which figures stand in the ratio of about 30, 31, and 25. It will thus be seen that the boiler which is best under one condition of working is not necessarily best under other conditions.

These various comparisons have been carried through at somewhat more trouble than seems to be warranted by the not very definite results obtained. They are, however, of value as indicating how thoroughgoing comparisons can be made where the conditions are fully known, and one point at least has been clearly shown up—a point which cannot be too strongly emphasized—viz., that perfect combustion is of far more importance, both as regards the efficiency of a boiler and the power to be got out of it, than is, within limits, either the amount of heating surface or its arrangement.

I am, Gentlemen,

Yours faithfully,

C. E. STROMEYER.

Chief Engineer.

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